L-399

ARR June 1942

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
June 1942 as
Advance Restricted Report

STRESSES AROUND RECTANGULAR CUT-OUTS IN SKIN-STRINGER PANELS UNDER AXIAL LOADS

By Paul Kuhn and Edwin M. Moggio

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

STRESSES AROUND RECTANGULAR CUT-OUTS IN SKIN-STRINGER PANELS UNDER AXIAL LOADS

By Paul Kuhn and Edwin M. Moggio

SUMMARY

The calculation of the stresses around cut-outs is discussed on the basis of a simplified application of the shear-lag theory previously published. Experimental stringer strains were measured around a systematic series of cut-outs. The test results indicate that the proposed method of calculating the stringer stresses is acceptable as a basis for stress analysis. A few measurements were made of shear stresses in the sheet, but a separate experimental investigation on these stresses is desirable because their maximum values are too highly localized for strain readings with ordinary gage lengths.

INTRODUCTION

The analysis of the stress distribution around cut-outs in stiffened shell structures is a difficult and complex problem. A theoretical basis for such an analysis exists in the form of the so-called shear-lag theory, but the practical application of this theory necessitates a prohibitive amount of arithmetic. This difficulty was overcome by a system of simplifying assumptions for the analysis of cut-outs that was introduced in a comprehensive paper on shear lag (reference 1). Extensive experimental verification of the reliability of these assumptions is highly desirable, because the cut-out problem is recognized as one of the most important problems in the design of shell structures. The present paper furnishes experimental evidence on one particular phase of the problem; it deals with rectangular cut-outs in plane skin-stringer panels under axial loads. The main emphasis has been placed on the stresses in the stringers, but the question of shear stresses in the sheet has also been treated to some extent.

METHOD OF ANALYSIS

Basic Assumptions and General Principles of Analysis

The structure to be analyzed is a skin-stringer panel as shown in figure 1(a). The rectangular cut-out is assumed to be bounded by two stringers and by two transverse ribs A-A. The thickness of the sheet is assumed to be constant as is the cross-sectional area of the stringers. The number of stringers is assumed to be large, and the cut-out is assumed to be centrally located. The panel is assumed to be long, compared with the width of the cut-out. The external load is applied in the form of a uniform stress σ_o applied at the ends of the panel.

The internal stresses existing in the panel are obtained by the superposition of the stresses caused by the two loading cases indicated in figures 1(b) and 1(c). In case I, shown in figure 1(b), external stresses equal to σ_o are assumed to be applied at the stringers where they are interrupted by the cut-out in addition to the stresses σ_o acting at the ends of the panel. The stress distribution existing in this case is simply a uniform axial s stress σ_o throughout the panel.

In case II, shown in figure 1(c), no external forces are assumed to act at the ends of the panel, but external forces are assumed to be applied to the stringers where they are interrupted by the cut-out. These forces are assumed to be equal in magnitude but opposite in direction to the corresponding forces acting in case I. The forces acting in case II are termed "liquidating" forces (reference 1) because their superposition on the forces of case I reduces the stresses in the interrupted stringers to zero along the boundaries A-A of the cut-out. The liquidating forces constitute a self-equilibrated system of forces; consequently, by St. Venant's principle, the stresses caused by the liquidating forces become negligible at large distances from the cut-out, spanwise as well as chordwise.

The calculation of the stresses caused by the liquidating forces of case II constitutes the main part of the problem. When this problem has been solved, it is only necessary to add everywhere the uniform stress σ_o corresponding to case I to obtain the final answer.

The calculation of the stresses is divided into two groups of calculations that are based on independent assumptions: namely,

(1) Calculation of the stringer stresses in the net section between the two ribs A-A

(2) Calculation of the stresses in the gross section

The transition between the two sets of stresses occurs in a relatively short region of transition surrounding the transverse ribs, as shown by the experimental evidence. For convenience of calculation, the transition regions are assumed to be infinitely short and located at the transverse ribs. The calculated stresses therefore show discontinuities at the ribs.

The symbols and the coordinate axes used are shown in figure 2. Under the assumptions made, symmetry exists about the longitudinal center line and about the transverse center line. Calculations will therefore be made for only one quadrant, and all forces specified refer to one-half the structure unless otherwise stated.

Stresses in the Net Section

Stresses in the stringers.- If A_b denotes the cross-sectional area of the interrupted stringers contained in the width b (fig. 2), then the liquidating force distributed over this width is

$$F_b = \sigma_o A_b \tag{1}$$

This force causes a reaction F_a of equal magnitude in the continuous stringers contained in the width a of the net section

$$F_a = F_b = \sigma_o A_b \tag{2}$$

The stresses σ_n caused by the force F_a are assumed to follow the law of chordwise distribution (reference 1)

$$\sigma_n = \sigma_{n_{max}} e^{-y/b} \tag{3}$$

By integration across the net section it is found that

$$\sigma_{n_{max}} = \sigma_o \frac{A_b\ a}{A_a\ b\left(1 - e^{-a/b}\right)} \tag{4}$$

where A_a is the cross-sectional area of the continuous stringers contained in the width a. The total maximum stress is therefore

$$\sigma_{max} = \sigma_{n_{max}} + \sigma_o = \sigma_o\left[1 + \frac{A_b\ a}{A_a\ b\left(1 - e^{-a/b}\right)}\right] \tag{5}$$

The expression in brackets is the stress-concentration factor referred to the basic stress σ_o. More significant is the stress-concentration factor referred to the average stress over the net section, the average stress being

$$\sigma_{av} = \frac{F_a}{A_a} + \sigma_o = \sigma_o\left(1 + \frac{A_b}{A_a}\right) \tag{6}$$

The stress-concentration factor referred to σ_{av} is

$$\frac{\sigma_{max}}{\sigma_{av}} = \frac{1 + \dfrac{A_b\ a}{A_a\ b\left(1 - e^{-a/b}\right)}}{1 + \dfrac{A_b}{A_a}} = C \tag{7}$$

This factor is shown graphically in figure 3, where $t_a = A_a/a$ and $t_b = A_b/b$.

For a homogeneous plate $(t_a = t_b)$ the stress-concentration factor approaches 2 for a very small cut-out $(a/b \rightarrow \infty)$. For comparison, it may be recalled that the stress-concentration factor for a small circular hole is 3.

For design purposes, it may be assumed that the stress in any given stringer is constant between the two ribs A-A. Actually, there is some change in stress in the vicinity of the ribs.

<u>Shear stresses in the sheet.</u>- At the transverse center line, the shear stresses in the sheet caused by the liquidating forces are zero for reasons of symmetry. At the ribs, the shear stress may become nearly equal to the

shear stress in the gross section for reasons of continuity of strain if the ribs are not sufficiently effective. No method has been developed thus far for calculating the variation of the stress between these two limits; such a method, when develcped, would also give the change of stringer stress between the ribs A-A.

Stresses in the Gross Section

Basic principles of calculation.- The stresses in the gross section are calculated by using the device of the substitute single stringer (reference 1). In this method all stringers loaded in the same direction are assumed to be combined into a single stringer located at the centroid of the group. Figure 4 shows in broken lines the actual panel and in heavy, full lines the substitute single-stringer panel. The stresses in the substitute panel are computed by simplified forms of the formulas given in reference 1.

The substitution indicated in figure 4 implies the assumption that the stresses caused by F_b are distributed uniformly over the width b and that the stresses caused by F_a are distributed uniformly over the width a. The first assumption, although not in very close agreement with the experimental results, is sufficiently close for most design purposes. The second assumption, which differs from the one made in reference 1, was made as a compromise to obtain reasonable agreement between test results and calculations as well as a convenient method of calculation.

It follows from St. Venant's principle that the stresses caused by F_a must be negligible when y is very large; the assumption of uniform distribution of the stresses caused by F_a must therefore be restricted to a finite width, which may be considered as a participating, or effective, width. On the basis of the tests, this width is taken as equal to 2b with the understanding that it may be changed as more test data become available. The calculation of the stresses will now be considered in detail.

Stringer stresses.- At the transverse ribs, the stress in any one continuous stringer caused by the liquidating forces is

$$\sigma_{g_o} = \frac{F_a}{A_{a_e}} \qquad (8)$$

The effective area A_{a_e} is equal to A_a if $a \overline{<} 2b$. If $a > 2b$, only a width $a = 2b$ is considered to be effective.

With increasing distance x from the rib, the stresses σ_g decrease according to the formula (reference 1)

$$\sigma_{g_x} = \sigma_{g_o} e^{-Kx} \tag{9}$$

where K is the shear-lag parameter (reference 1) defined by

$$K^2 = \frac{G_e t}{E d}\left(\frac{1}{A_{a_e}} + \frac{1}{A_b}\right) \tag{10}$$

where G_e is the effective shear modulus and t is the thickness of the sheet. The width d of the substitute panel is

$$d = \frac{1}{2}(a_e + b) \tag{11}$$

with $a_e = a$ if $a \overline{<} 2b$

or

$$a_e = 2b \quad \text{if} \quad a > 2b$$

The total stress in a continuous stringer in the gross section is, therefore,

$$\sigma = \sigma_o + \sigma_{g_o} e^{-Kx} \tag{12}$$

When $a \overline{<} 2b$, the stress just at the rib is equal to σ_{av}, and the expression for σ may be written

$$\sigma = \sigma_o + (\sigma_{av} - \sigma_o) e^{-Kx} \tag{12a}$$

The stress caused by the liquidating force in any one cut stringer is

$$\sigma_{g_x} = \sigma_{g_0} e^{-Kx} = \frac{F_b}{A_b} e^{-Kx} = \sigma_0 e^{-Kx}$$

The total stress in a cut stringer is therefore

$$\sigma = \sigma_0 - \sigma_{g_x} = \sigma_0 \left(1 - e^{-Kx}\right) \tag{13}$$

A pictorial presentation of the stringer stresses around a cut-out is given in figure 5.

Shear stresses.- The shear stress in the sheet of the substitute panel is given by the formula (reference 1)

$$\tau = \frac{F_b K}{t} e^{-Kx} \tag{14}$$

In the substitute panel, this shear stress is uniformly distributed over the width d (fig. 4). In the actual panel, the shear stress is probably concentrated to some extent near the corner of the cut-out.

Stresses in the transverse ribs.- The transverse ribs are loaded by the shear forces in the adjacent sheet, the ribs being stressed in compression when the panel is in tension. The running load applied to the rib may be taken as

$$\tau t = F_b K \tag{15}$$

distributed over the width d. Since the ribs lie entirely in the region of transition, the methods of calculation given thus far should not be expected to hold very closely.

Approximate application of theory to box beams.- When a skin-stringer panel is used as cover of a box beam, the basic stress σ_0 usually varies along the axis of the beam, although the designer attempts to approach the condition of uniform stress. In such cases, the theory may be applied as a practical approximation method by computing first the stresses that would exist if there were no cut-out.

Separate values of the liquidating stresses are thus found for each end of the cut-out; the effects of these liquidating stresses are computed separately for each end and are superposed on the basic stresses. In the net section, the stringer stresses may be assumed to vary linearly between the values computed for the two ends.

EXPERIMENTAL INVESTIGATION

Test Objects and Test Procedure

In order to obtain experimental verification for the methods of calculation described, the panel shown in figure 6 was built. It consisted of a sheet of 17S-T aluminum alloy 0.0266 inch thick. To this sheet were riveted 15 stringers of 53S-T aluminum alloy, each stringer consisting of 2 opposing strips with a cross section of 0.101 inch by 0.751 inch each. The spacing of the stringers was 2.51 inches.

The load was applied by the lever arrangement shown in the figure. A whippletree arrangement was used at each end in order to insure uniform distribution of the stresses at the ends.

Strains were measured by Tuckerman strain gages with a gage length of 2 inches. The gages were used in pairs on both sides of the specimen. Strains were measured at corresponding points in all four quadrants; each point, except those in figures 8 and 15, plotted on the figures therefore represents the average of four stations or eight gages.

The panel was originally built without a cut-out. A survey of the strains in the stringers was made for this condition in order to study the uniformity of stress distribution in this most favorable case. After this test, cut-outs of progressively increasing width were made in the center of the panel from one to nine cut stringers. Figure 6 shows the cut-out in which seven stringers were cut. All cut-outs were of the same length. Surveys were made in each case of the strains in the stringers over the region where the influence of the cut-out was noticeable.

On the panel without cut-outs, strain readings were taken at 0, 20, 40, 60, 80, 100, and 0 percent of the maximum load applied. In the rest of the tests on the large panel, readings were taken at 0, 50, 100, and 0 percent of the maximum load applied. Check runs were made when the final reading at no load differed from the initial reading by more than 100 pounds per square inch.

A special test was made of the panel with the largest cut-out by removing the standard stringers adjacent to the cut-out and substituting stringers with about twice the cross-sectional area; the individual strips had a cross section of 0.2512 inch by 0.9986 inch.

When these tests had been completed, the large panel was cut into the four smaller panels shown in figure 7 and these panels were tested in the new NACA 1,000,000-pound testing machine. With this set-up, it was possible to obtain much higher stresses than with the loading lever; the accuracy of the strain readings was consequently higher. In as much as the panels had only a small number of stringers, they were not considered as sufficiently typical of actual cases to warrant complete strain surveys; stringer strains were therefore measured only at the center of the net section by Tuckerman strain gages. In addition, electrical strain gages were used at the four corners of the cut-outs to measure the strains in the sheet at 45° to the axes; these gages are visible in figure 7. Since the axial stresses in the sheet are small at these stations, the 45° strains give an approximation to the shear stress in the sheet. The usual precaution of using the gages in pairs on both sides of the sheet was taken. Load increments of 3 kips were used.

Accuracy and Reliability of Measurements

The accuracy of the Tuckerman readings at any given station is estimated to be ± 1 percent; the accuracy of the electrical gages, ±4 percent, taking into account in both cases reading error, temperature error, and deviation of individual calibration factors from unity. The term "accuracy of a measurement" as used herein denotes the relation between the observed strain and the true strain (due to loading) at the surface of the specimen between the gage points.

The term "significant accuracy of measurement" is introduced here to denote a concept of practical importance: namely, the relation between the observed strain and the true average stress in the vicinity of the gage station. The significant accuracy is the sum of the following errors:

errors of inaccuracy of measurement as previously defined; errors due to inaccurate value of Young's modulus used to convert strains to stresses; and, finally, errors due to failure of rivets to insure integral action of the structure. Past experience has shown that the third error is by far the largest when accurate strain gages are used. In shear-lag tests, for instance, on a beam with a cover similar in construction to the present panel it was found by direct measurement that the stress in the sheet differed by as much as 20 percent from the stress in the stringers near the root of the beam. The error in total internal force that results from considering the stringer stress as representative of the sheet stress is, of course, much less, because the sheet constitutes only a part of the total cross-sectional area.

A complete study of the inaccuracies defined would be very difficult and tedious. It is important, however, to gain some idea of the significant accuracy because it has some bearing on the comparison between experiment and calculation.

The strain survey on the panel without cut-out was made in order to assess the significant accuracy of the cut-out tests. Figure 8 shows the observed stresses in the form of plots of chordwise stress distribution. Two sets of points are shown: stresses based directly on the strain reading at maximum load, and stresses based on the slope of the best-fitting straight line drawn through the experimental points on the load-strain plots. A study of figure 8 shows the following:

1. The average stress over an entire cross section deviates from the average at any other section by a maximum of about 3 percent.

2. Local variations from the mean may amount to about 6 percent.

These local variations may affect several adjacent stringers in a smoothly varying manner or they may affect only one stringer.

In the panel without cut-outs, the rivets are theoretically not needed to distribute the stresses except near the ends. In panels with cut-outs, however, the rivets are needed to distribute the stresses; such nonuniformities as are displayed by the panel without cut-outs may therefore be regarded as minimum values, and larger nonuniformities may be expected in panels with cut-outs. Figure 8 indicates that the significant accuracy of stresses measured over a small region (say of a width or length equal to three stringer spaces) should not be expected to be better than about 6 percent. This conclusion should be borne in mind when comparing experimental and calculated maximum stresses.

No corresponding study of significant accuracy was made for the shear stresses in the sheet. It is probably safe to assume, however, that the significant accuracy of the shear-stress measurements is somewhat less than that of the stringer-stress measurements, because the accuracy of the gage is less and because the shear stress varies rapidly in a nonlinear manner along the span.

Comparisons between Experimental and Calculated Results

The results of the tests on the large panel with cut-outs are presented in figures 9 to 14. Figure 15 shows the results obtained on one of the small panels, and figure 16 shows graphically the shear stresses in the 4 small panels. Table 1 gives the data necessary for computing the maximum stringer stresses as well as the computed and the observed maximum stresses for all panels. Table 2 gives the computations for the shear stresses in the four small panels for test loads of 20 kips on the whole panel.

Stringer stresses in net section.- From the point of view of a practical stress analyst, the most important item is the comparison between experimental and observed maximum stresses. The maximum stringer stress in each panel occurs in the stringer bounding the cut-out and within the net section. The numerical values are listed in table 1.

The ratios of observed maximum stress to calculated stress are plotted in figure 17 against the ratio a/b. The tentative curve faired through the test points gives most weight to the panels which conform best with the assumption that there are many stringers uniformly distributed. It will be noted that the three points definitely below unity belong to panels which do not conform very well with these assumptions; two points belong to panels in which only a single stringer is cut, and one point belongs to the panel with very heavy stringers along the cut-out. The results indicate that the method of calculation presented in this paper tends to be somewhat unconservative for wide cut-outs and conservative for narrow cut-outs. The faired curve shown may be used tentatively to correct the results of calculation. It is advisable, however, to use great caution when using a correction factor below unity because the point at $a/b = 6$ does not represent a typical panel and the course of the curve for $a/b > 3$ is, therefore, uncertain.

Figure 17 includes two points obtained by photoelastic tests of reference 2 on homogeneous plates; the homogenous plate may be considered as the limiting case of a skin-stringer panel with infinitely many stringers. The stress values had to be scaled from rather small figures given in reference 2 (pp. 577 and 664) and are consequently not very accurate; in spite of this fact, the results agree quite well with the results obtained on the large panel.

It is important to note that, contrary to what might be expected, the stress distribution over the net section is far from uniform even in the limiting case when the net section contains only two stringers, as in panels 7 and 9. (See fig. 15.) An analogous statement was made in reference 2 (p. 486) with respect to the stresses in a tension plate having a large circular hole and, consequently, a narrow net section. This observation is of practical importance, particularly in view of the tendency of the theory to become unconservative for narrow net sections, as noted above.

Stringer stresses in gross section.- A study of figures 9 to 14 indicates that the calculated stringer stresses in the gross section are, in general, in satisfactory agreement with the observed stresses. One consistent discrepancy is apparent in all panels: The actual stress in the stringer bounding the cut-out is lower than the calculated stress, and the stress in the adjacent uncut stringer is correspondingly higher. The practical importance of this discrepancy is probably confined to indicating the need for providing some extra margin in the design of the rivets in the first uncut stringer.

In cases where the influence of the cut-out is appreciable along the free edges of the panel (figs. 12, 13, 14), it will be noted that the stress in the edge stringers reaches its maximum not in the net section but outside it. This phenomenon was also found to exist in homogeneous plates with rectangular cut-outs by means of photoelastic tests (reference 2, p. 664) and has been proved to exist by the theory of elasticity in the related case of a tension plate with a large hole (reference 2, p. 487).

Shear stresses in the sheet.- Inspection of table 2 and of figure 16 indicates that in panels 7, 9, and 10 the agreement between calculated and observed shear stresses is satisfactory. In panel 8, the observed stress is considerably higher than the calculated stress. Additional experimental evidence would be required to decide whether this is an exceptional case or an indication that the theory tends to be unconservative.

The measured shear stresses are not the maximum shear stresses; it is difficult to measure the maximum values because they are highly localized, and quantitative data obtained by strength tests would be useful.

It might be mentioned that the strain readings obtained with the 45° gages were corrected to account for the presence of some longitudinal stress in the sheet at the gage locations. The corrections were based on calculated stresses and were small (average about 4 percent).

Stresses in the ribs.- No measurements of stresses in the ribs were made, because the use of filler pieces underneath the ribs between stringers resulted in too large an uncertainty concerning the cross-sectional area of the ribs.

When an attempt was made to apply the full test load to the large panel shown in figure 6, the ribs at the cut-out buckled very badly. An approximate analysis of this failure indicated that the load on the rib may be estimated by using equation (15), but the analysis depends very critically on several factors which are not known with any degree of accuracy; this failure of the ribs cannot, therefore, be considered as quantitative evidence.

CONCLUSIONS

The experimental evidence presented indicates that the method of cut-out analysis presented in this paper may be used as a basis for stress analysis.

The maximum stringer stresses calculated by this method should be increased by 5 to 10 percent when the cut-out is wide ($a > 2b$).

Additional studies on the magnitude of the maximum shear stresses are desirable.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Kuhn, Paul, and Chiarito, Patrick T.: Shear Lag in Box Beams - Methods of Analysis and Experimental Investigations. NACA Rep. No. 739, 1942.

2. Coker, E. G., and Filon, L. N. G.: A Treatise on Photo-Elasticity. Univ. Press (Cambridge), 1931.

TABLE 1

MAXIMUM STRINGER STRESSES IN NET SECTIONS OF TEST PANELS

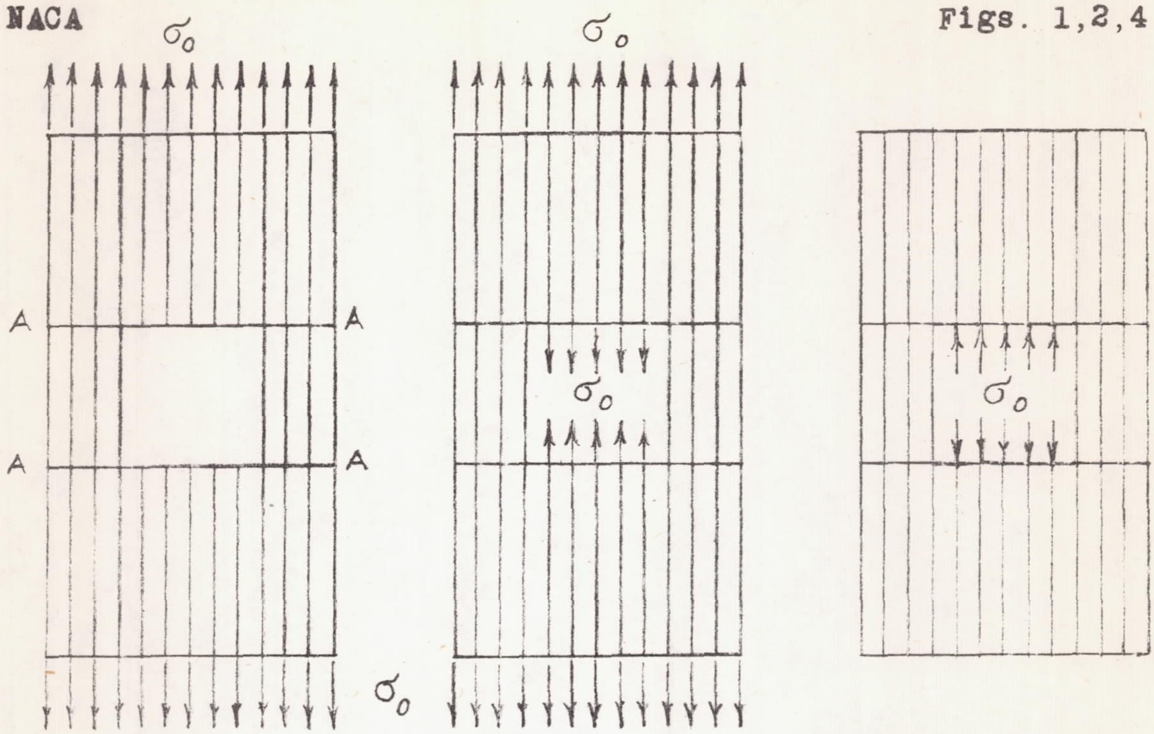
Specimen	Number of stringers	Number of cut stringers	a (in.)	b (in.)	A_a (sq in.)	A_b (sq in.)	P (lb)	Calculated σ_{av} (lb/sq in.)	Calculated $\frac{\sigma_{max}}{\sigma_{av}}$	Calculated σ_{max} (lb/sq in.)	Observed σ_{max} (lb/sq in.)	$\frac{\text{Obs } \sigma_{max}}{\text{calc. } \sigma_{max}}$
1	15	1	15.06	2.51	1.485	0.133	4,472	3,015	1.412	4,255	3,650	0.858
2	15	3	12.55	5.02	1.266	.352	4,472	3,537	1.375	4,860	4,780	.983
3	15	5	10.04	7.53	1.047	.571	4,472	4,275	1.288	5,505	5,820	1.057
4	15	7	7.53	10.04	.828	.790	4,472	5,400	1.204	6,505	7,210	1.110
5	15	9	5.02	12.55	.609	1.009	4,472	7,350	1.134	8,340	9,020	1.081
6	15	9	5.02	12.55	.959	1.009	5,426	5,655	1.110	6,280	5,970	.950
7	8	4	2.51	6.27	.390	.462	10,000	25,640	1.114	28,570	30,600	1.071
8	8	2	5.02	3.77	.609	.243	10,000	16,420	1.230	20,200	20,250	1.002
9	7	3	2.51	5.02	.390	.352	10,000	25,640	1.130	29,000	29,400	1.014
10	7	1	5.02	2.51	.609	.133	10,000	16,420	1.236	20,280	18,850	0.929

TABLE 2

CALCULATION OF SHEAR STRESSES IN SHEET

$$\left[K = \left[\frac{Gt}{Ed}\left(\frac{1}{A_a} + \frac{1}{A_b}\right)\right]^{\frac{1}{2}} = \left[\frac{0.385 \times 0.0266}{d}\left(\frac{1}{A_a} + \frac{1}{A_b}\right)\right]^{\frac{1}{2}};\ (\tau t)_{max} = F_b K\ ;\ \ x = 1.50 \text{ in.}\right]$$

Specimen	K	$(\tau t)_{max}$ (lb/in.)	τ_{max} (lb/sq in.)	Kx	e^{-Kx}	Calculated τ (lb/sq in.)	Observed τ (lb/sq in.)	$\frac{\text{Obs. } \tau}{\text{Calc. } \tau}$
7	0.1048	568	21,330	0.157	0.855	18,200	19,200	1.054
8	.1160	331	12,420	.174	.840	10,420	12,400	1.190
9	.1212	575	21,600	.182	.834	18,000	16,800	.935
10	.1578	283	10,610	.237	.789	8,380	8,600	1.024



(a) - Actual loads (b) - Case I (c) - Case II

Figure 1. - Panel with cut-out.

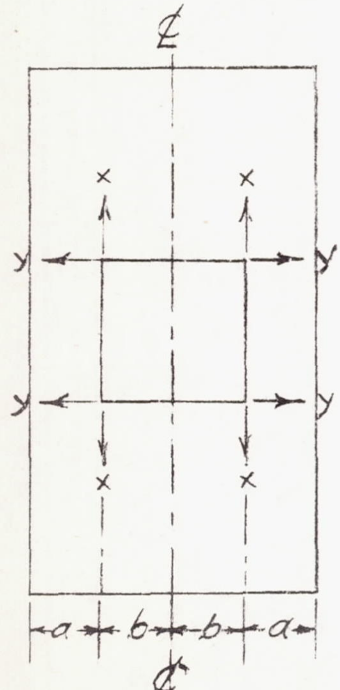


Figure 2. - Convention for coordinates.

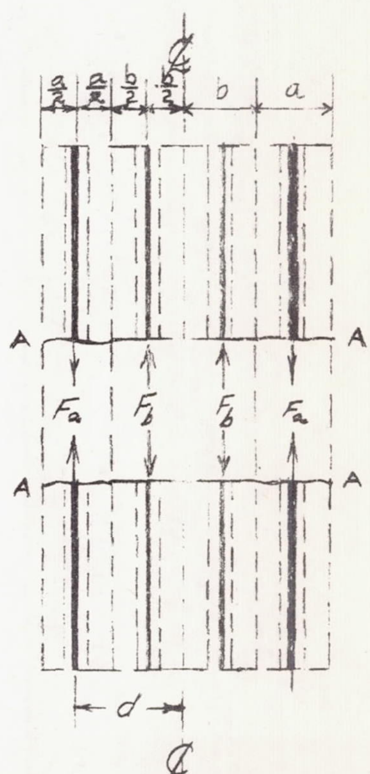


Figure 4. - Substitute single-stringer panel.

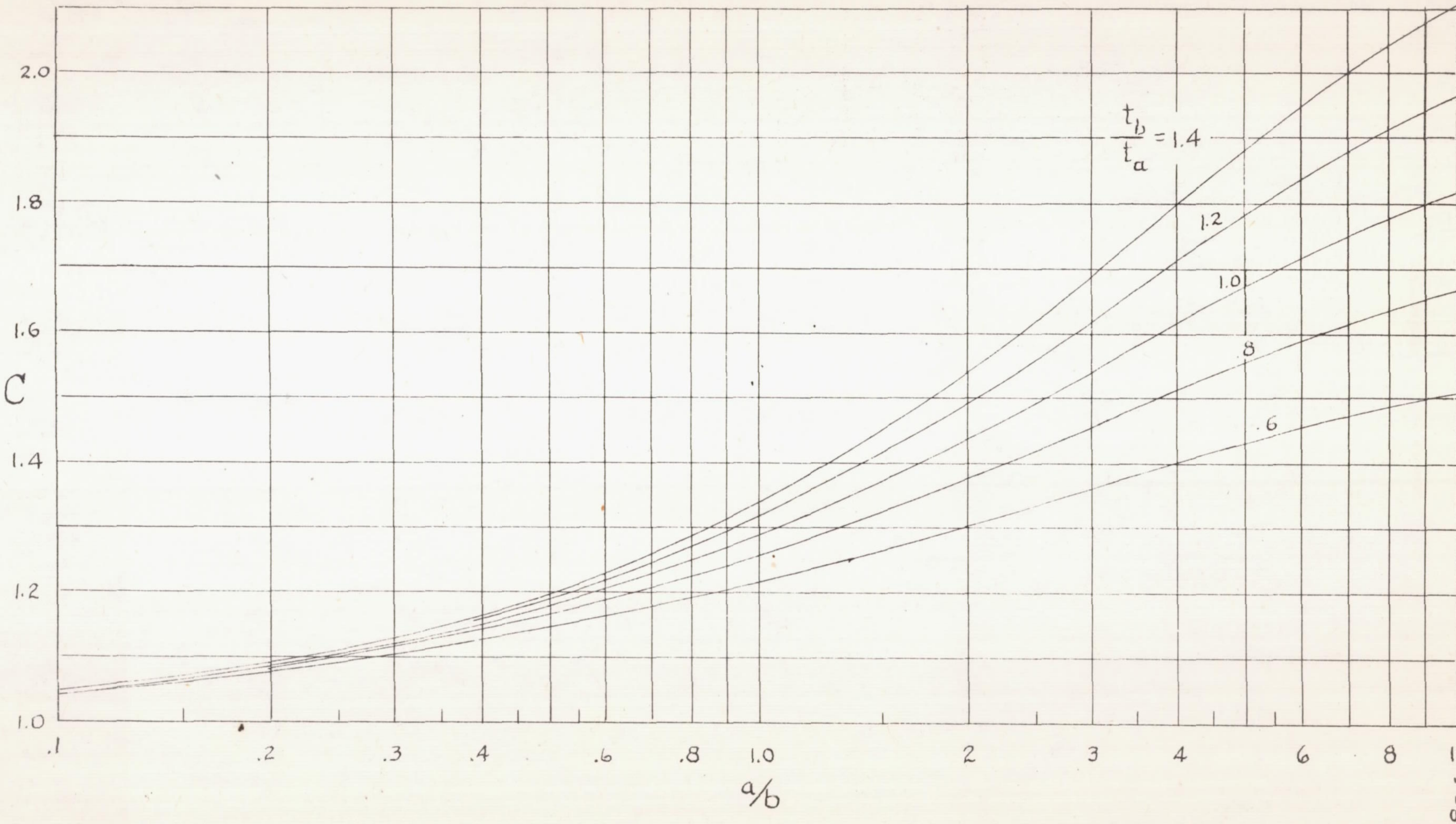


Figure 3.- Stress-concentration factor for stringer stresses.

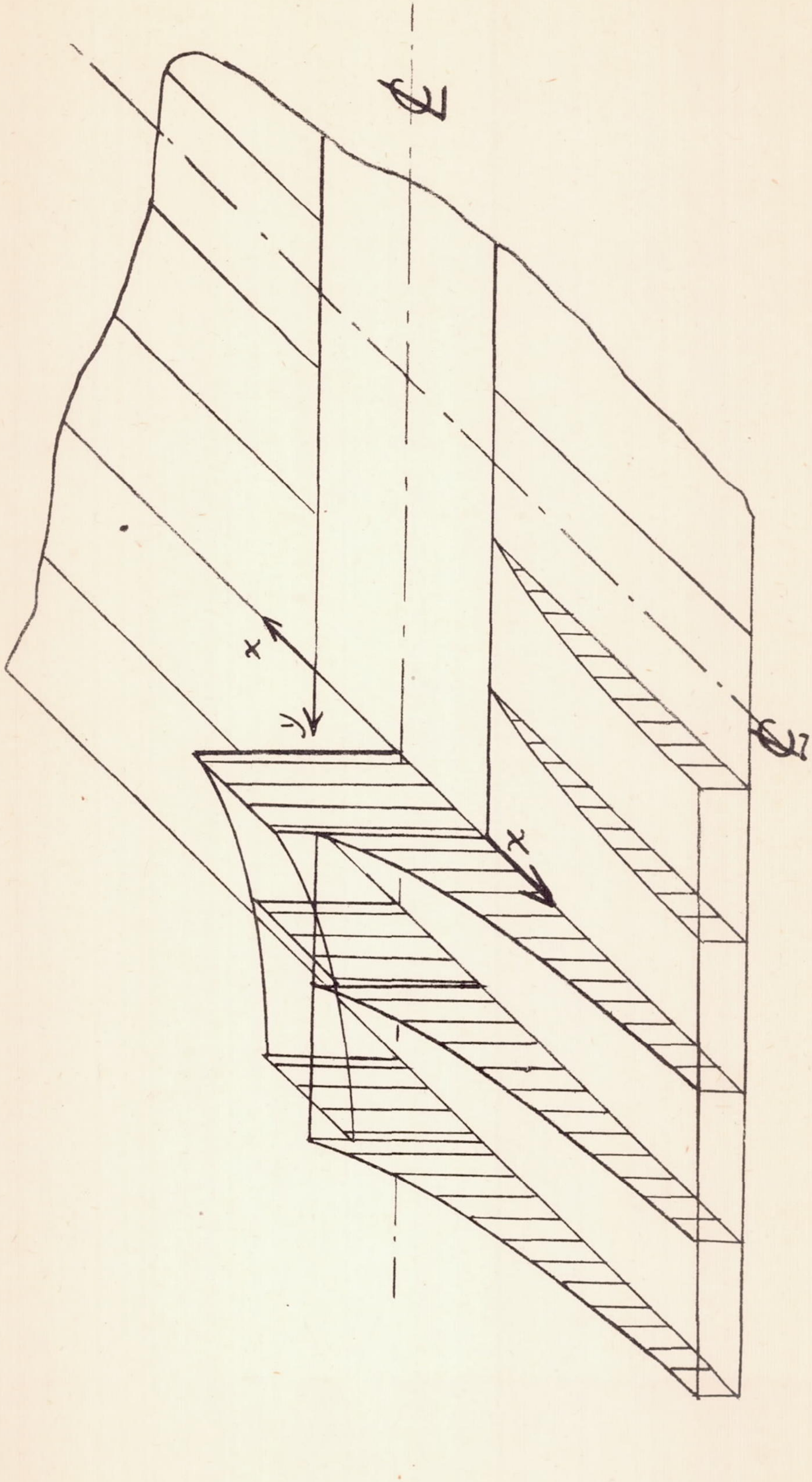


Figure 5.- Distribution of calculated stringer stresses.

L-399

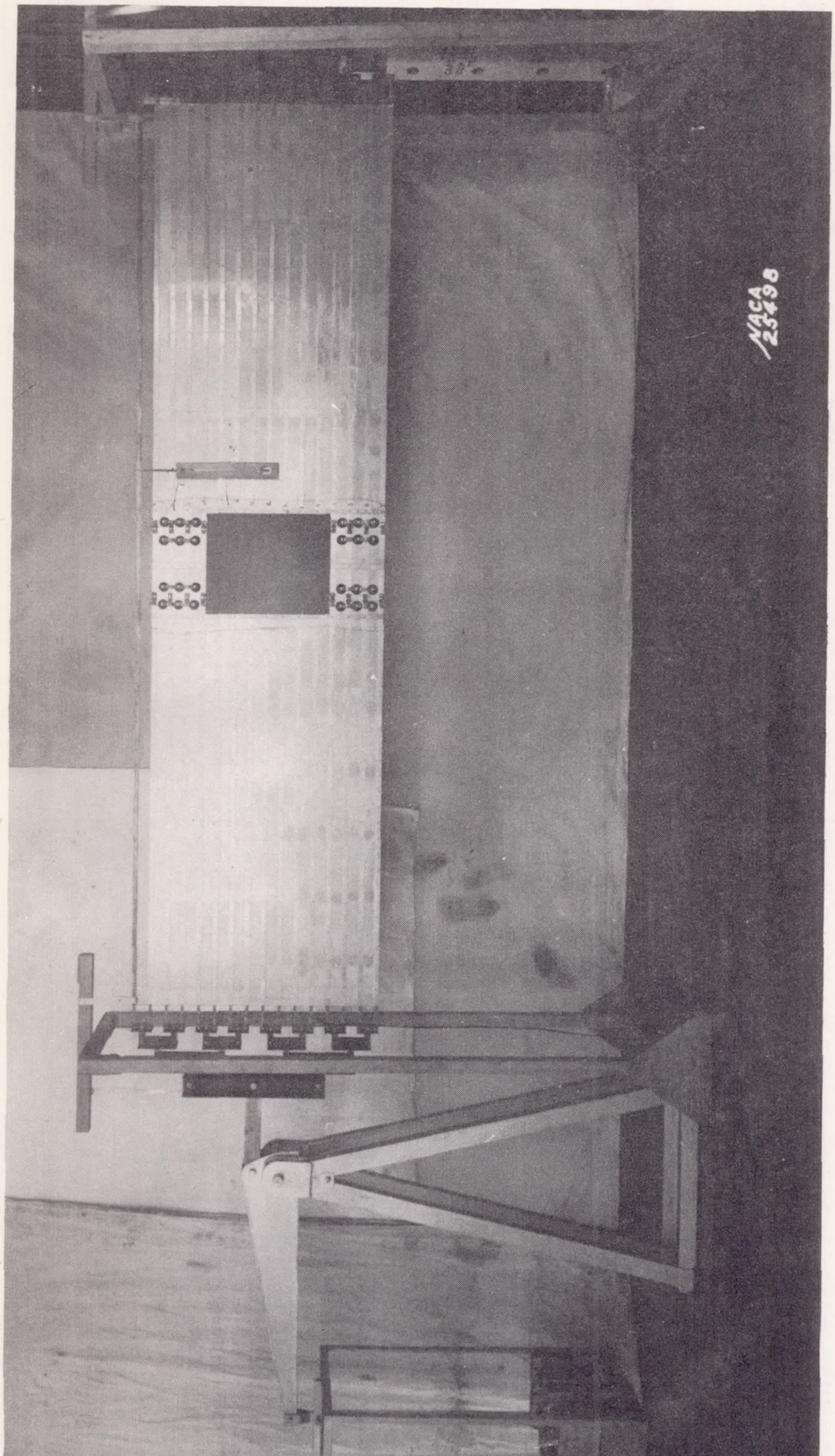


Figure 6.- Large panel set up for test.

L-399

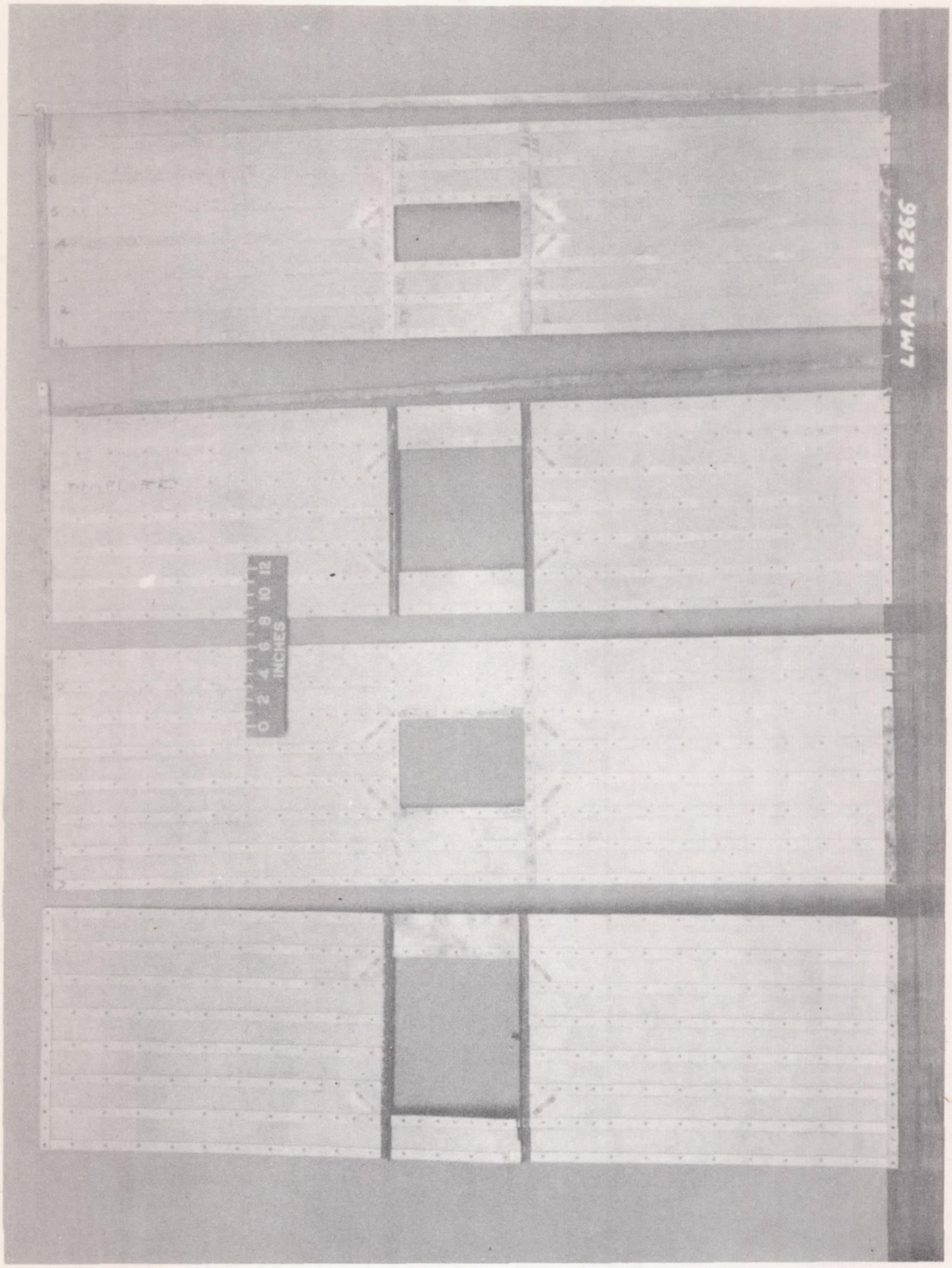


Figure 7.- Small panels after tests.

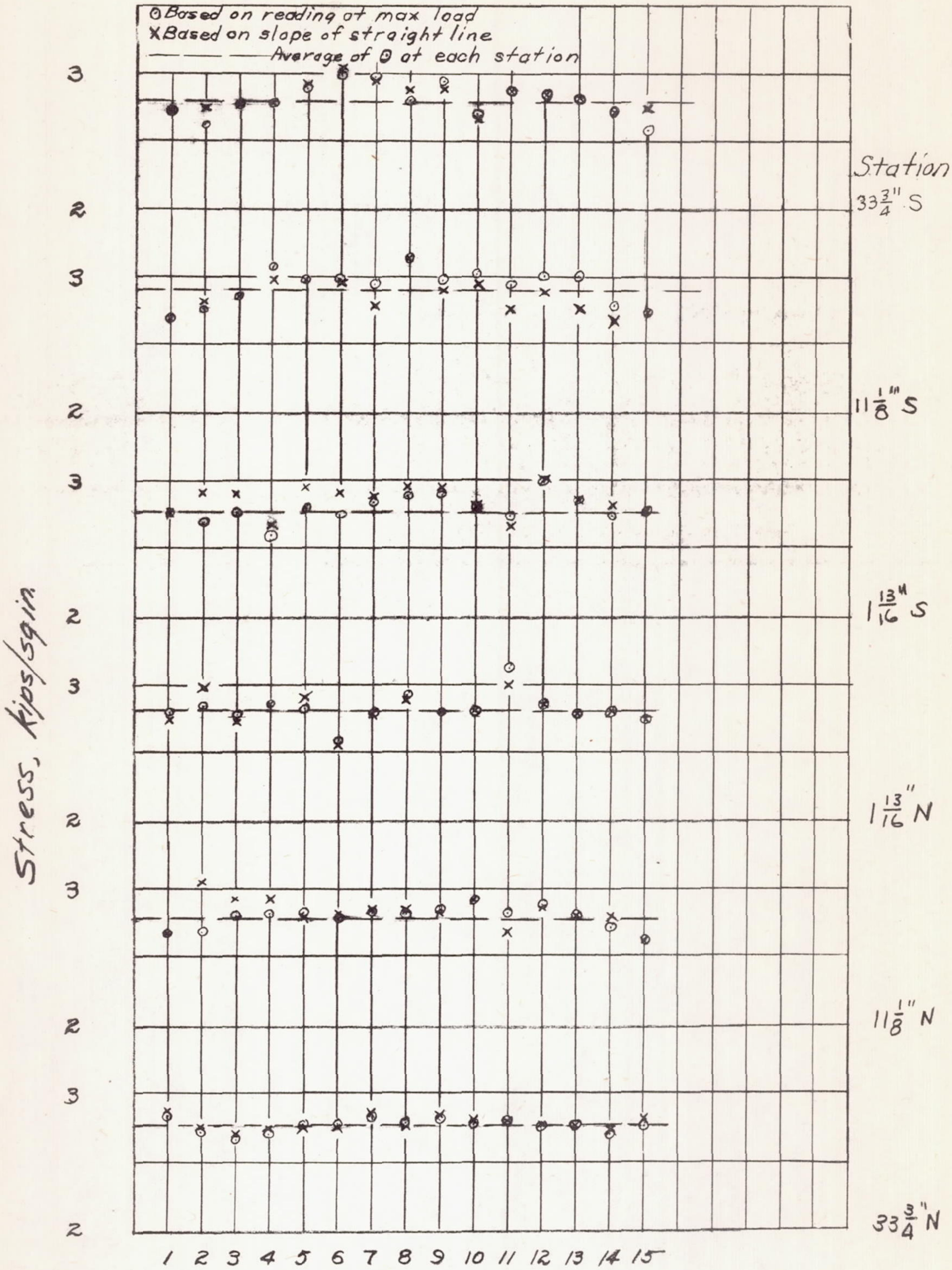


Figure 8.- Chordwise distribution of stringer stresses in panel without cut-out.

L-399

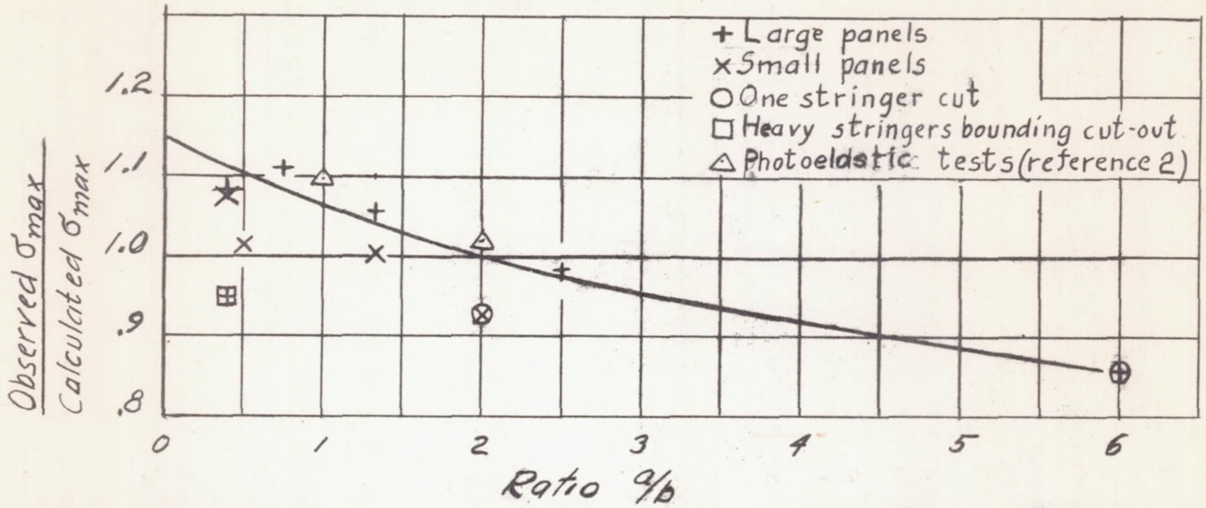


Figure 17.- Ratios of observed maximum stringer stress to calculated stress.

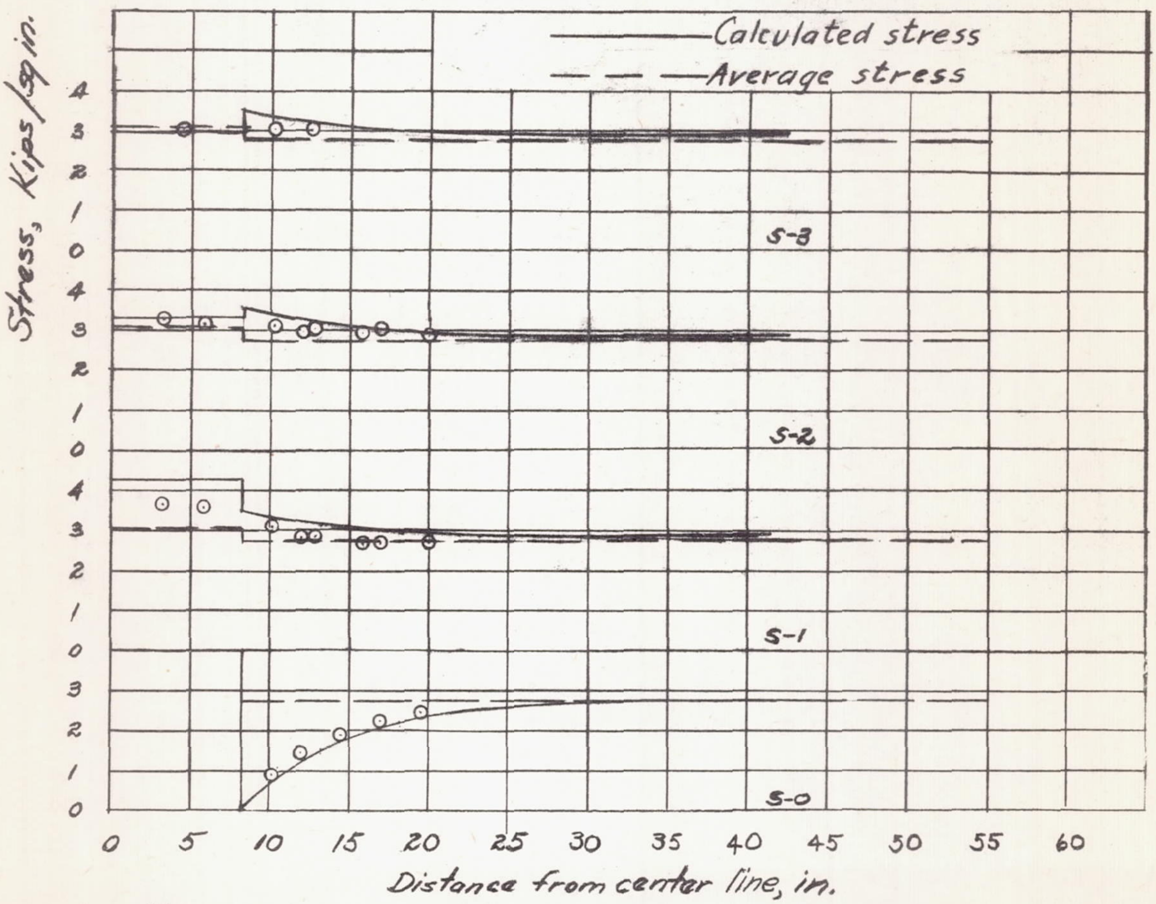


Figure 9. - Stringer stresses in large panel with one stringer cut.

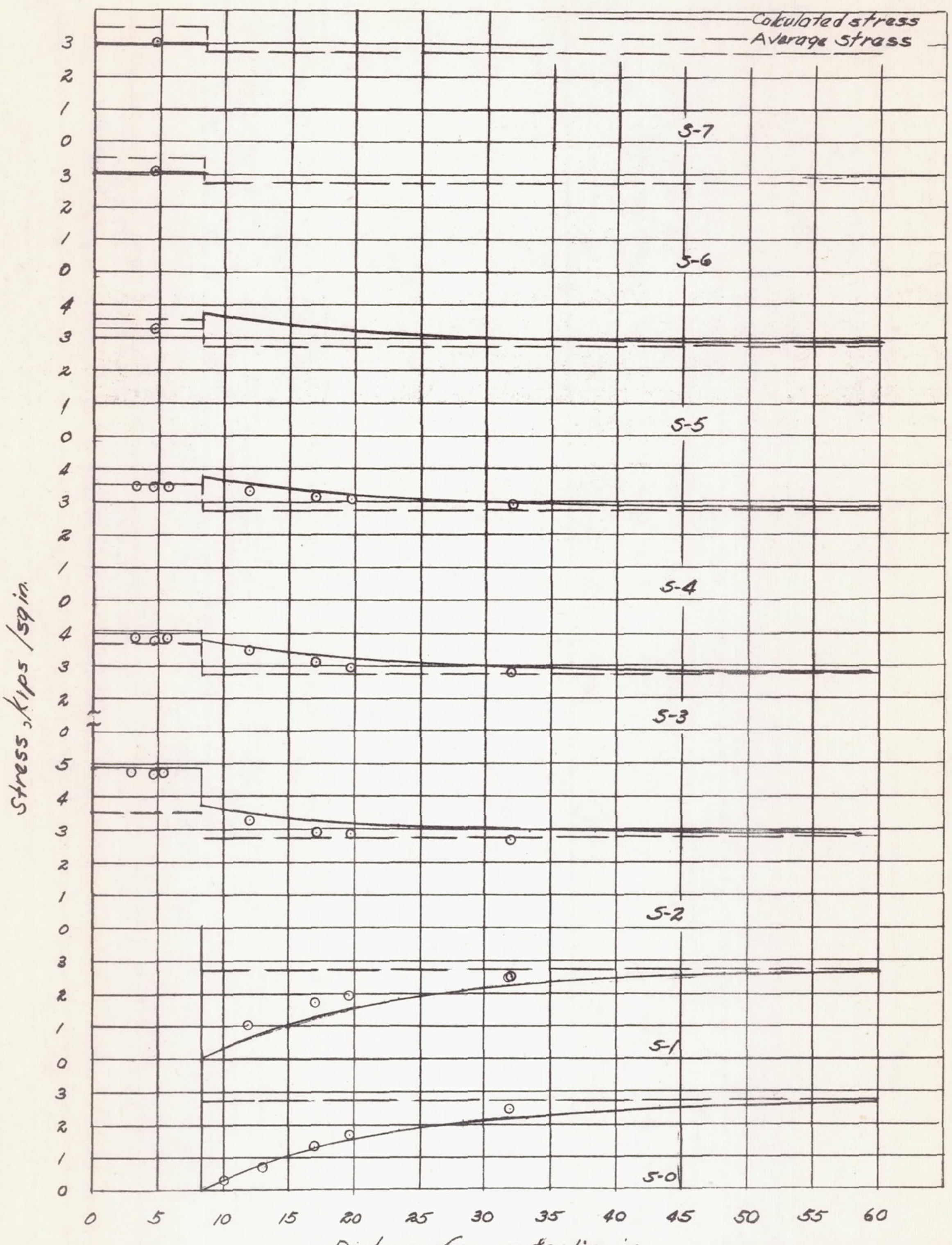


Figure 10.- Stringer stresses in large panel with three stringers cut.

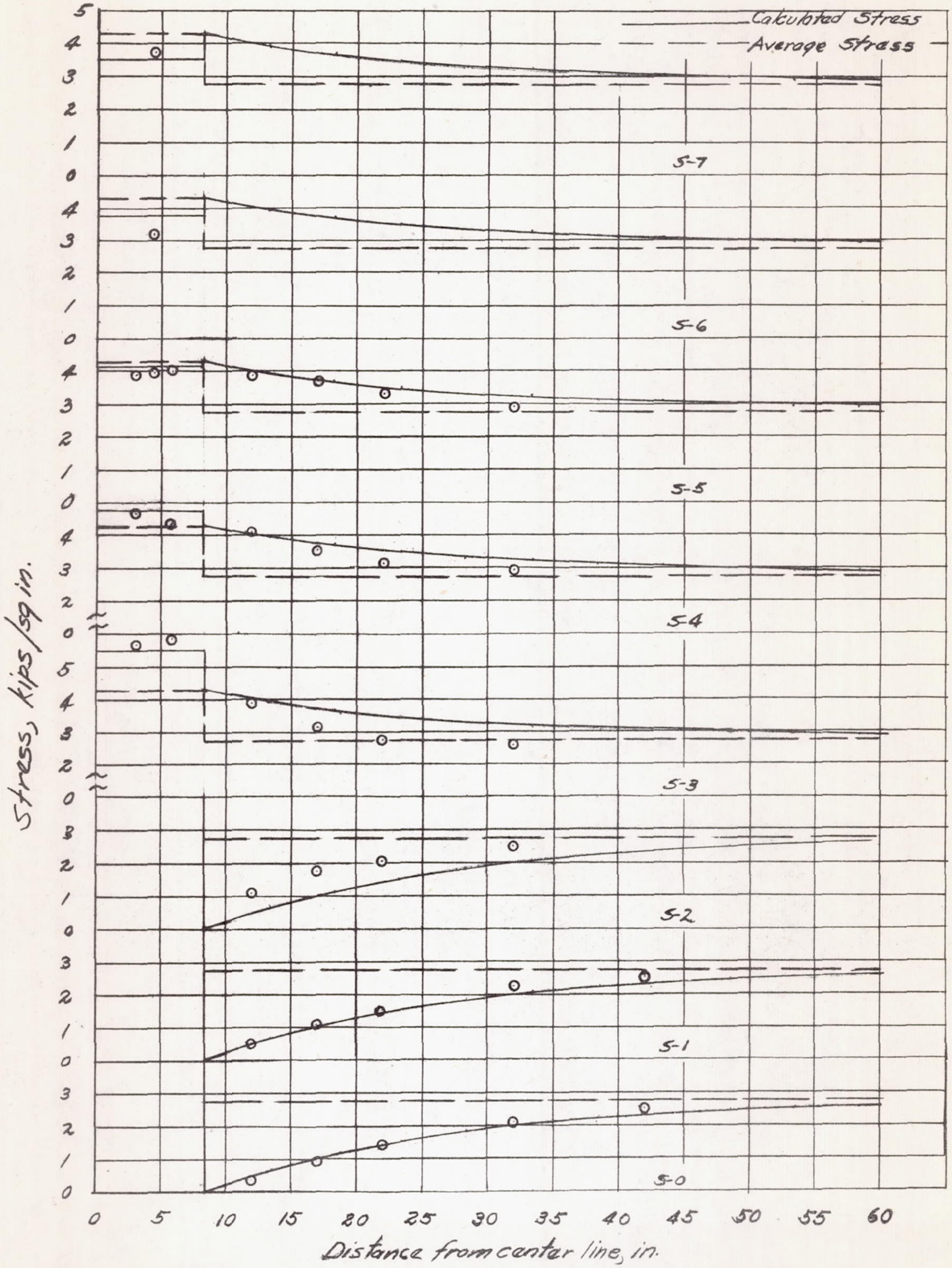


Figure 11.- Stringer stresses in large panel with five stringers cut.

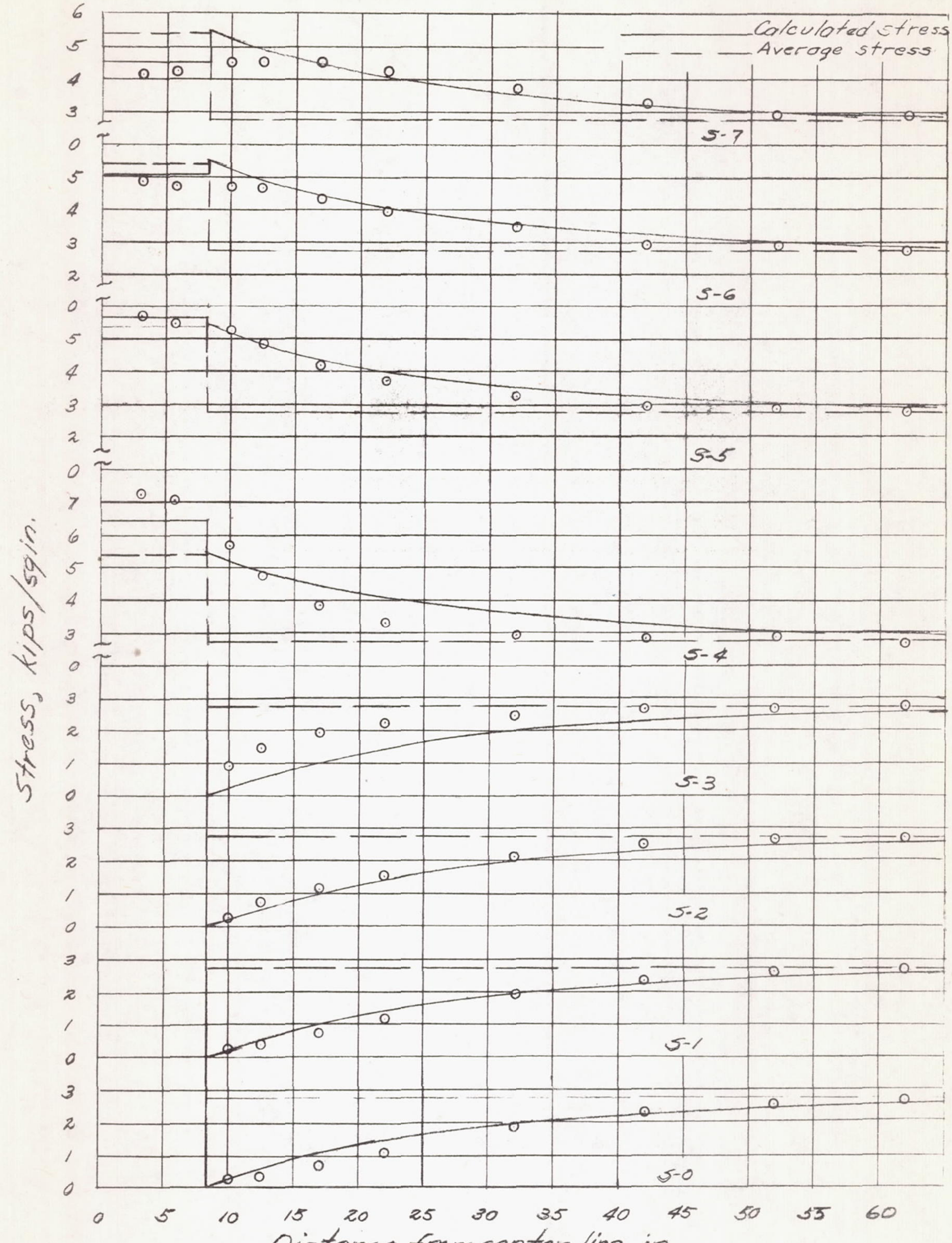


Figure 12. - Stringer stresses in large panel with seven stringers cut.

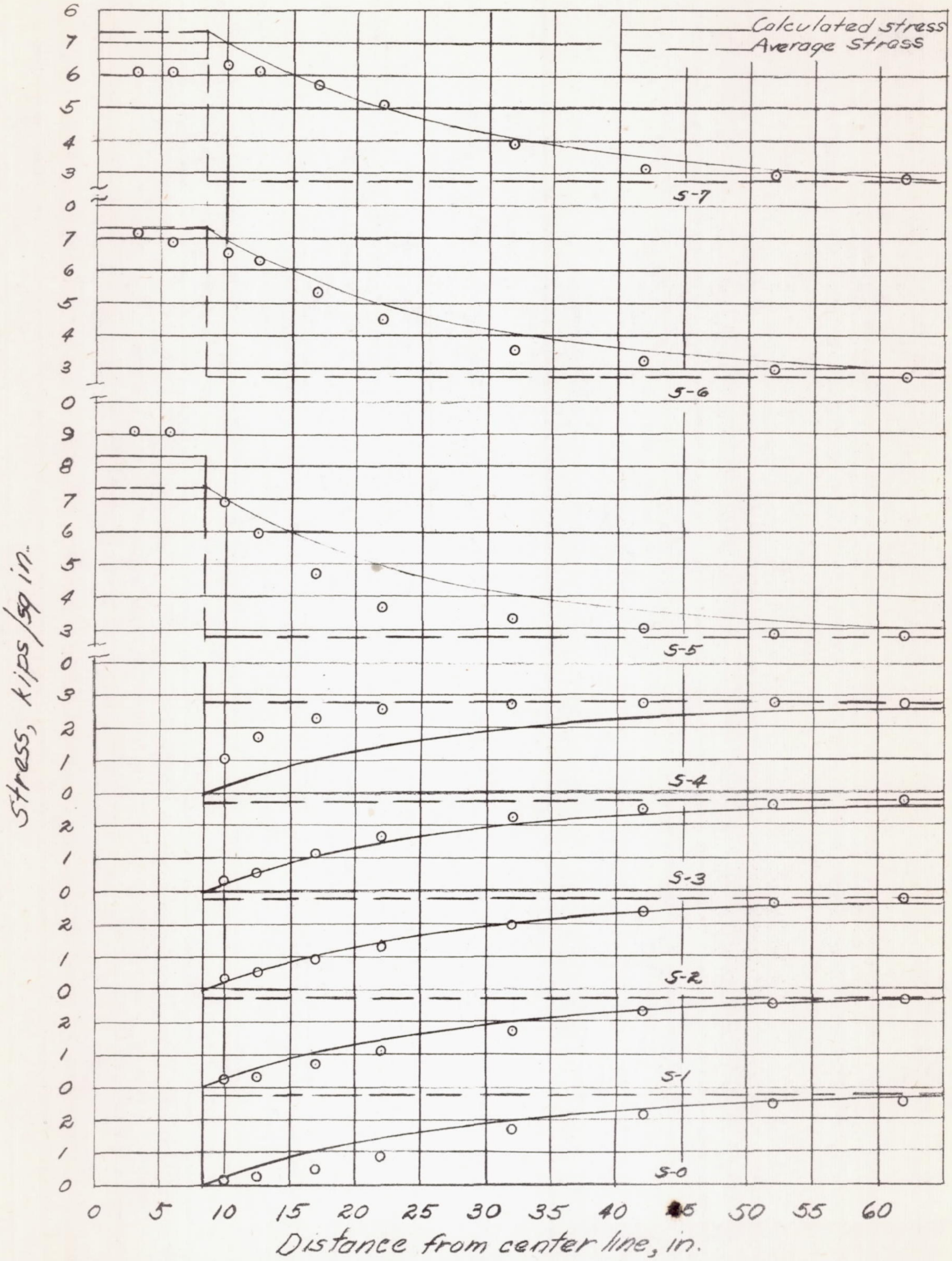


Figure 13.—Stringer stresses in large panel with nine stringers cut.

L - 399

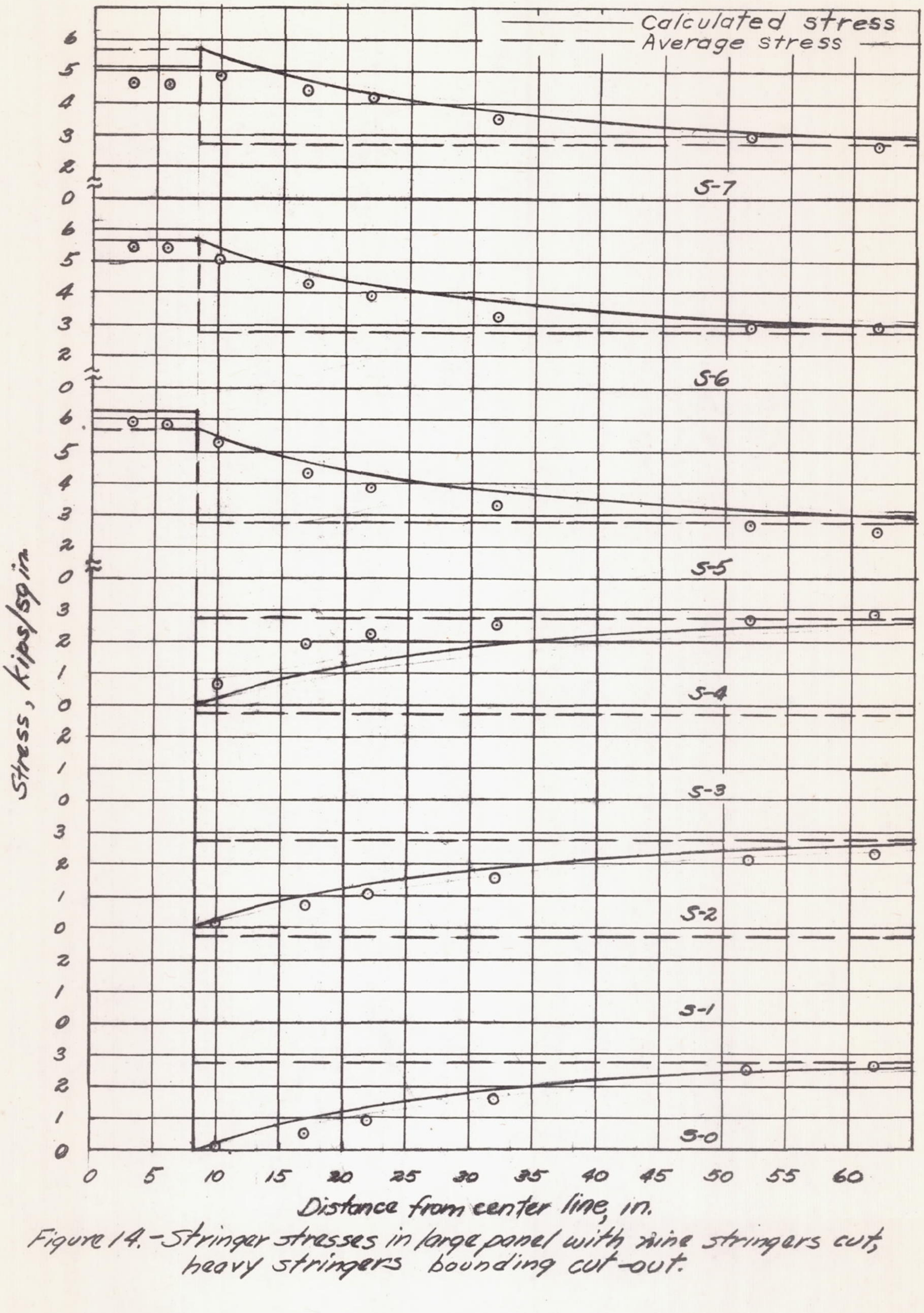


Figure 14.- Stringer stresses in large panel with nine stringers cut; heavy stringers bounding cut-out.

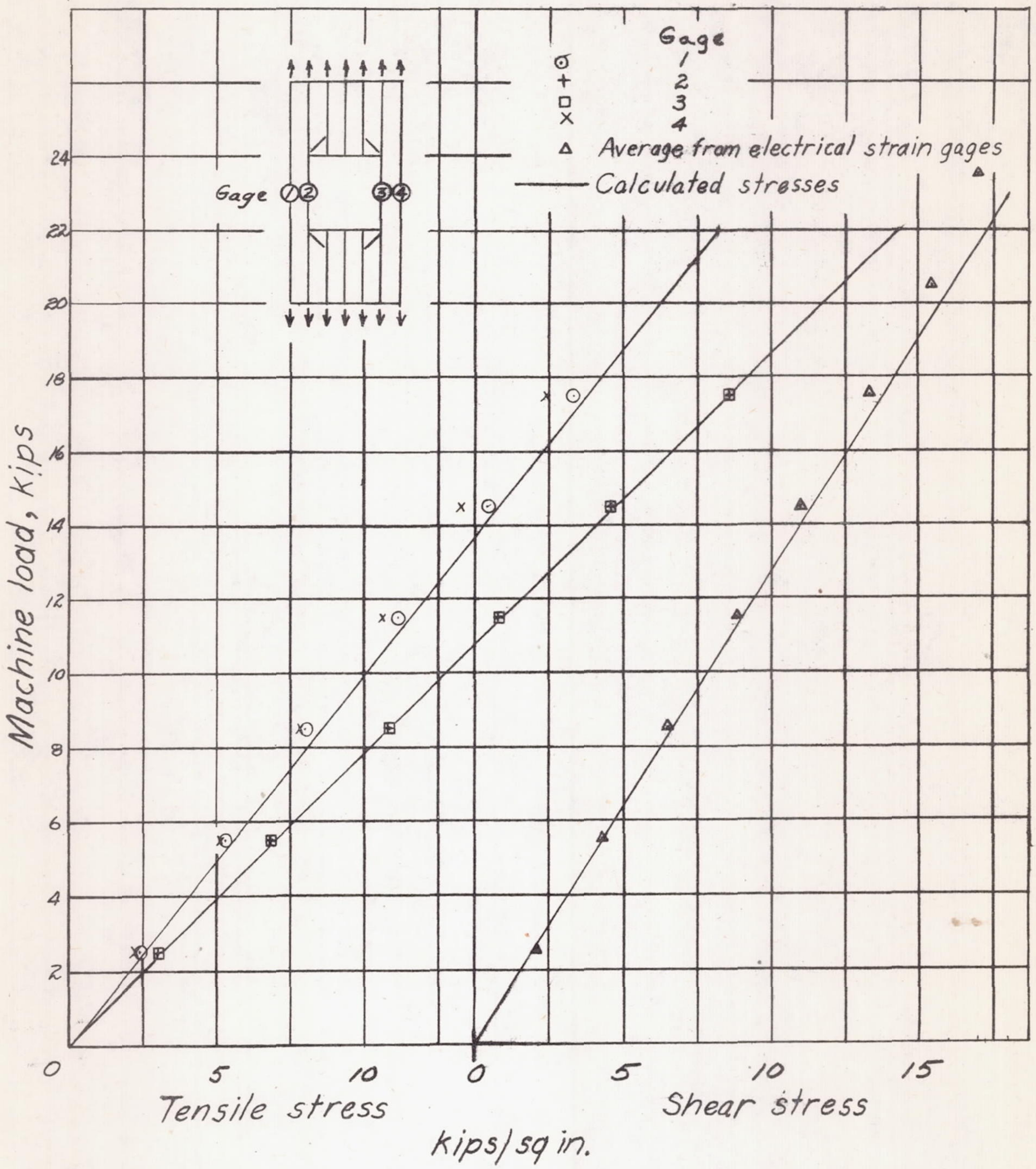


Figure 15.- Stresses in small panel number 9. Panel load is equal to 1/8 machine load.

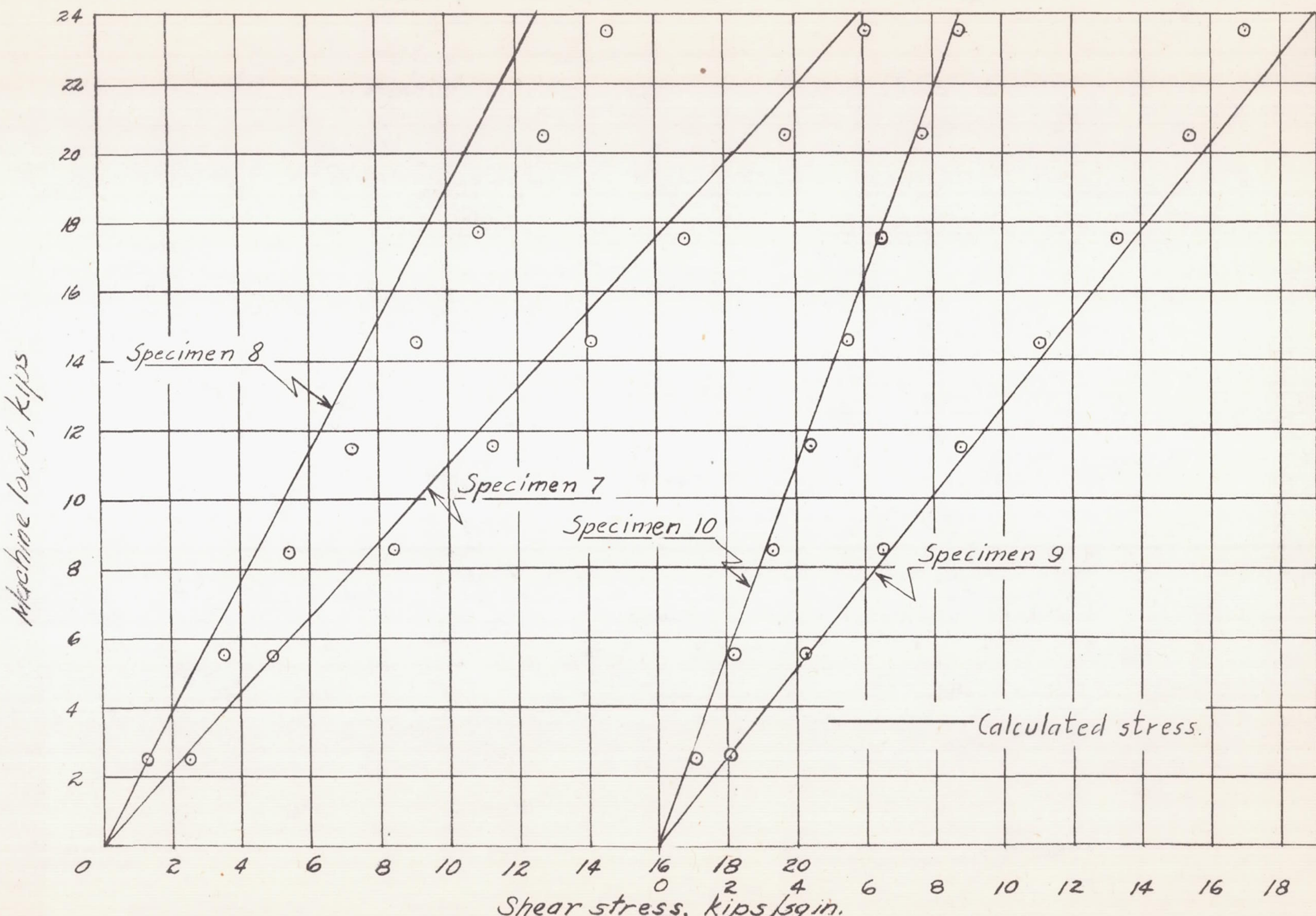


Figure 16. Shear stresses in 4 small panels.
For panels 7 and 8, panel load equals machine load; for panels 9 and 10, panel load equals 7/8 machine load.